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Experiments in the Use of Vapor-Spray Equipment[1]

By O. K. Hedden, *associate agricultural engineer*, and R. M. Merrill, *agricultural engineer, Farm Mechanical Equipment Research Division, Bureau of Agricultural Chemistry and Engineering*

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INTRODUCTION

The use of water vapor produced by heat, as a means of applying insecticides and fungicides to vegetation, attracted the attention of investigators many years ago. The earliest apparatus utilizing heat for this purpose was adapted from steam cleaners used for cleaning the outer surfaces of buildings. With the adaptation of this type of equipment to the cleaning needs of automotive shops, a lighter, more portable unit resulted and interest revived in an investigation of the possibility of using such equipment for dispersing fungicides and insecticides. The experiments discussed in this publication were made to compare the effectiveness of such equipment with the hydraulic sprayers in common use.

The hydraulic machinery ordinarily used to apply sprays utilizing water as the carrying medium for the insecticide or fungicide, consists of a piston type, reciprocating pump with suitable automatic

[1] The experimental field work upon which this circular is based was carried on jointly by the Bureau of Agricultural Engineering and the Bureau of Entomology and Plant Quarantine of the U. S. Department of Agriculture; the Ohio Agricultural Experiment Station; and the Michigan Agricultural Experiment Station. Acknowledgment is here made of the assistance of the following individuals in locating and arranging for experimental plots, in assisting in the mixing of sprays, in making chemical analyses, and in determining the amounts of spray residue and the degree of insect and plant disease control: G. A. Runner L. F. Steiner, associate entomologists, G. W. Still, assistant entomologist, J. E. Dudley, Jr., entomologist T. E. Bronson, junior entomologist, and J. E. Fahey, assistant chemist, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture; H. C. Young, chief, P. E. Tilford, J. D. Wilson, and H. F. Winter, associate plant pathologists, Department of Botany and Plant Pathology, and J. S. Houser, chief, and C. R. Cutright, associate entomologist, Department of Entomology, Ohio Agricultural Experiment Station; and Ray Hutson, head, Department of Entomology, and E. J. Rasmussen, research associate in horticulture, Michigan Agricultural Experiment Station. The cooperation of many individual growers in permitting the use of blocks of their commercial plantings for experimental purposes is also gratefully acknowledged.

devices to control and indicate pressure. For most purposes the spray mixture is broken into tiny droplets as it is forced through a small orifice in a spray gun or a spray nozzle. The fineness of the spray is

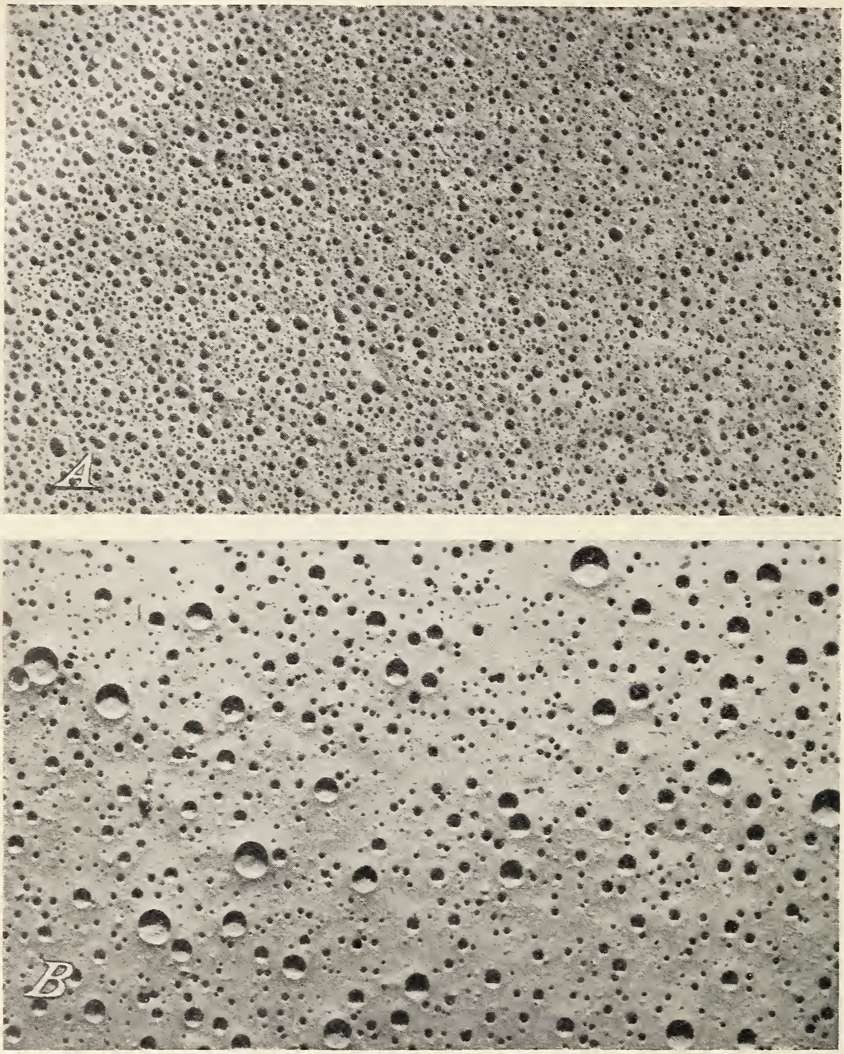

FIGURE 1.—*A*, Spray from vapor nozzle. Orifice diameter 0.269 inch. Delivery 1.16 gallons per minute at 125 pounds per square inch. *B*, Spray from conventional-type spray nozzle. Orifice diameter 0.0626 inch. Delivery 1.3 gallons per minute at 350 pounds per square inch. × 8.

determined largely by the pressure and the size of orifice, a larger orifice being used when greater driving effect is desired for spraying tall trees.

Preliminary tests which resulted in the studies discussed here were made early in 1935, to determine whether the use of water vapor as a spray medium might be desirable. Apparatus consisting of a vertical

coal-fired steam boiler for heating water, and means of injecting spray chemicals into the vapor line was arranged in the laboratory. A slide showing water droplets produced by a vapor sprayer and another showing a similar spray from a comparable hydraulic machine are shown in figure 1. The preparation and study of many slides under controlled conditions and utilizing some of the more common spray formulas as well as water alone gave results of which figure 1 is representative. These laboratory tests indicated that sprays produced by this method were more finely divided and evenly dispersed than those produced by the use of hydraulic spray machinery. Observation of vapor jets issuing from various experimental nozzles led to the conclusion that, although the vapor did not appear to equal the ordinary spray in carrying power, it did, nevertheless, leave the nozzle with considerable driving energy. This force appeared to be sufficient to insure penetration and coverage of most foliage of normal density.

Another characteristic of vapor spray which appeared to be of importance was the effect that heat might have upon spray materials. Early experiments indicated that sulfur underwent a change in form which improved its adhesive qualities and that Bordeaux mixture was also affected by the heat to which it was subjected when applied by vapor spray. The use of this material at pressures above 100 pounds per square inch with corresponding increases in temperatures produced marked changes in color and a tendency toward coagulation. It appeared from these observations that heat would have the effect of increasing the activity of spray chemicals with the possibility of either beneficial or harmful results.

All of these initial experiments were encouraging, for the fineness and uniform dispersion gave the vapor spray ability to cover and wet surfaces quickly. Increased wetting power and chemical activity might lead to considerable reduction in water requirements, with a saving of labor and power necessary to apply the spray. With these thoughts in mind, field experiments were undertaken by the Bureau of Agricultural Chemistry and Engineering in cooperation with entomologists, pathologists, and chemists of the Ohio Agricultural Experiment Station at Wooster, Ohio, the Michigan Agricultural Experiment Station at East Lansing, Mich., and the Bureau of Entomology and Plant Quarantine of the United States Department of Agriculture.

EARLY EXPERIMENTAL APPARATUS

A portable machine of the type used for automotive cleaning purposes was obtained. It consisted of tubular water-heating coils and a gravity-feed oil burner with suitable fuel and water tanks and other accessories. Two chief disadvantages of the machine were its small capacity (five-eighths of a gallon per minute) and the inability of the oil burner to function properly when the unit was operated on uneven or rolling ground.

A larger machine, having a capacity of 1¼ gallons per minute and utilizing a pressure-feed, fuel-oil burner to heat the water and produce vapor, was procured. Since the effect of heat upon various chemicals in the sprayer could not be definitely foretold, it was decided that adding chemicals to the vapor on its way to the nozzle after leaving the heater would avoid considerable corrosion and chemical deposition in

the heater coils of the machine. A device for injecting chemicals in paste form was developed and attached to this sprayer. It proved unsatisfactory because the pressure necessary to force the paste into the vapor line squeezed the liquid from the paste in the pressure tube and prevented uniform feeding of the spray materials into the vapor line. Because of the slow rate at which chemicals were added, the heat also tended to dry the paste and increase the difficulty of uniform injection of active material. To overcome these difficulties a small reciprocating pump with mechanically operated, poppet-type

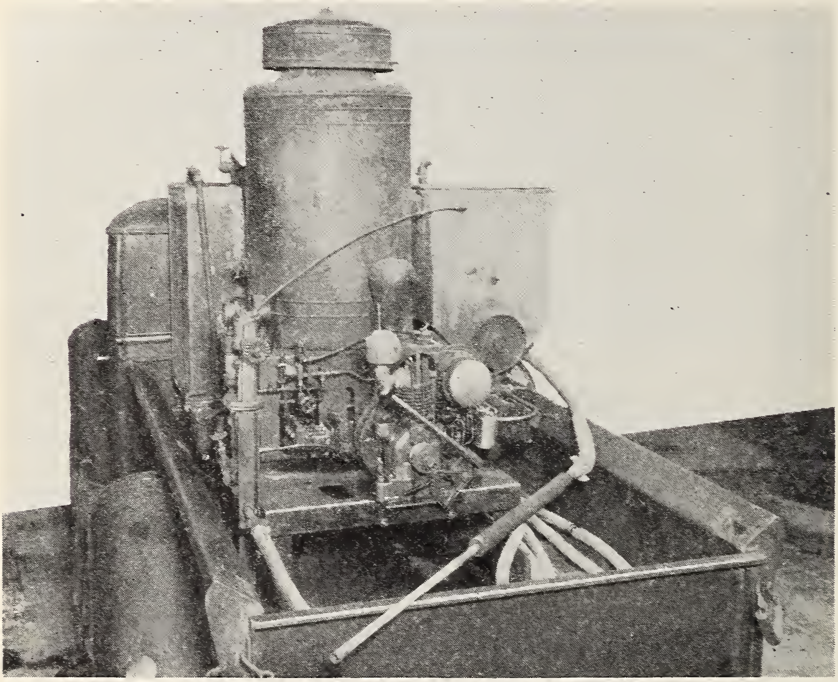

FIGURE 2.—Truck-mounted vapor sprayer.

intake valves and ball-type exhaust valves was procured. This pump was capable of injecting concentrated spray solutions into the vapor line at a known rate, so that any desired spray mixture could be had by mixing a solution of the proper concentration. The capacity of the sprayer was eventually increased to 2¼ gallons of spray per minute. This sprayer mounted in a truck for field use is shown in figure 2.

THE VAPOR-SPRAY MACHINE

The sprayer used during the last season of experimental work is shown diagrammatically in figure 3. The flow of water and of spray solution is indicated in this figure. The chains and shafts which made up the power-transmission system are shown as broken lines. All apparatus could be disconnected from the engine by the clutch shown near the engine in figure 3.

Both of the pumps used were of the horizontal, triplex, single-acting, outside-packed, reciprocating type. The cylinder head of the oil-and-solution pump was cast so that liquid passages of one cylinder

were entirely separate from the other two. The single cylinder pumped fuel oil and the other two pumped the concentrated spray solution into the vapor line. The delivery of 0.66 gallon of concentrate from these two cylinders combined with the delivery of 1.62 gallons of liquid from the water pump gave a discharge of 2.28 gallons of vapor spray per minute at a pressure of 100 pounds per square

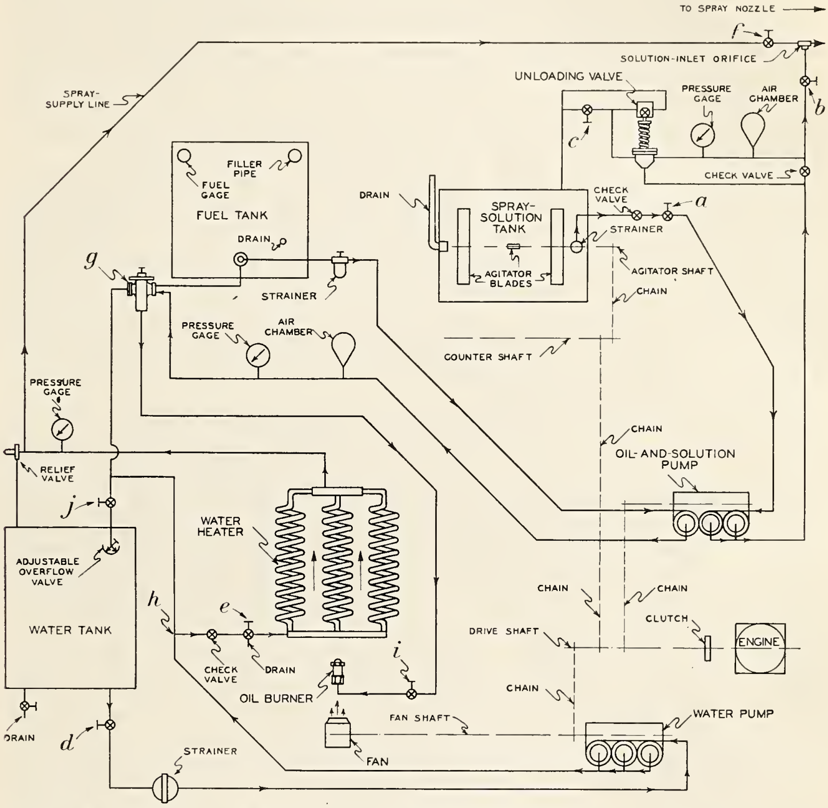

FIGURE 3.—Diagram of circulation system of vapor sprayer: *a*, Gate valve; *b*, control valve; *c*, manually operated valve; *d*, shut-off valve; *e*, drain valve; *f*, manually operated gate valve; *g*, no-water-cut-off and oil-pressure regulator; *h*, division in water line; *i*, gate valve close to burner; *j*, valve.

inch. The bore of each cylinder was three-fourths of an inch, with a ⅝-inch stroke.

Inlet valves were of the poppet type and valve passages less than eleven thirty-seconds of an inch in diameter containing a valve stem larger than five thirty-seconds of an inch in diameter appeared to offer considerable resistance to the flow of insoluble or foam-producing chemicals. Many such materials are used in spray work and consequently small pumps for work of this nature must have carefully designed fluid passages to insure free entry of fluid into the pump cylinders. Ball valves were used in the exhaust side of the pump. The use of stainless steel balls was found to be of vital importance because of corrosion of other metals by the unusually high concentrations of active materials in the solutions being pumped. Even

slight corrosion appeared to allow enough leakage in these valves to produce unreliable delivery from the oil-and-solution pump. It was also found desirable to limit the lift of these valves very closely to insure their quick return to the seating position after delivery of the cylinder charge to the discharge line.

The unloading valve (fig. 3) was set to prevent any concentrate from returning to the solution tank until a pressure of 180 pounds per square inch was reached. The usual operating pressure in the heater coils was 125 pounds per square inch. The corresponding pressure at the solution inlet orifice was 80 pounds per square inch. This drop in pressure permitted the injection of spray materials to be made more easily and reduced the effects produced by subjecting chemicals to high temperature and pressure when mixed with each other.

The spray-solution tank is shown in figure 2. This tank is 19 inches long, 17 inches wide, and 22¾ inches deep. Agitation of liquid in the tank was produced by three flat steel agitator blades 7 inches long, attached at their short central axis to a shaft rotating 100 revolutions per minute. Two of the blades were 2½ inches wide and the center blade was 1¼ inches wide. The agitation produced was a minimum sufficient to keep heavy material, such as lead arsenate, in suspension and was a little more than is desirable for material which produces foam when stirred vigorously.

The liquid leaves the solution tank through a strainer (fig. 3). This strainer was of corrosion-resistant copper-bronze screen having 18 meshes per lineal inch and provided 9.8 square inches of open screen. Lumps of insoluble materials, leaves, petals, twigs, and small unripe fruits were prevented from entering the pump intake by this screen. Providing ample screen area at this point is essential in order that accumulated debris will not interfere with ready movement of fluid to the pump. A check valve and a gate valve are placed in the intake line which conveys the concentrate from the solution tank to the oil-and-solution pump. This pump forced the fluid into the discharge line leading to the spring-operated unloading valve. If the control valve (fig. 3, *b*) is closed, pressure rises until it is considerably higher than pressures necessary to force solution into the spray line. The unloading valve then opens and permits concentrate to return to the solution tank. A manually operated valve (fig. 3, *c*) is also provided to permit the passage of concentrate back to the solution tank without pressure. An air chamber is provided to reduce shock in the pump and afford as smooth a flow of concentrate as possible. A pressure gage near the solution inlet indicates the pressure at which solution is delivered to the vapor line.

Solutions passing through the solution pump of this sprayer carried very heavy loads of insoluble materials in many instances. Pipe lines were kept as small in cross section as possible without too great an increase in internal flow resistance. The velocity of flow was thus high and deposits of insoluble materials did not collect in the pipe lines. The average velocity in the intake line was 90.8 feet per minute and in the discharge line 184.1 feet per minute.

Water for conversion to vapor is carried in the tank back of the truck cab (fig. 2). Liquid entering the suction line leading to the water pump passed through a manually operated shut-off valve (fig. 3, *d*) into a strainer. A screen of 40 meshes per lineal inch removed foreign material that might otherwise have prevented proper

operation of the water pump. The pump would not draw a full charge of water if the strainer became clogged with debris. Clogging was prevented by providing 23.7 square inches of unobstructed screen area in the strainer. It was then necessary to clean the strainer only after extended periods of operation when the water supply contained considerable dirt or scale. From the strainer water is drawn into the water pump and forced out into the discharge line. It passes through a check valve, past the drain valve (fig. 3, *e*) and into the water heater. This drain valve can be used to drain the heater coils and manifold in cold weather and permits blow-down of the coils for scale removal.

The water heater consists of six coils of ⅜-inch steel pipe containing a total of about 210 lineal feet and providing about 27 square feet of internal heating surface. All coils were connected to the same inlet manifold and to a single outlet manifold. They are enclosed in a cylindrical insulated steel shell shown in figure 2. The hot water passes through the spray supply line to a manually operated gate valve (fig. 3, *f*) where it can be released into the spray hose. A restriction nineteen sixty-fourths of an inch in diameter is located in the spray supply line to enable the pump to maintain the desired pressure and to facilitate the introduction of concentrate into the spray supply line. Without the venturi effect produced at the mouth of the inlet in the side of this restriction the heat and pressure cause many materials to solidify and quickly clog the passage admitting the solution into the spray supply line.

No. 1 or No. 2 domestic furnace oil can be used as fuel for the oil burner in the water heater. Oil is drawn from a tank through a strainer into the fuel pump from which it is forced to the no-water cut-off and oil-pressure regulator (fig. 3, *g*). A pressure gage and air chamber are connected to this line.

A water line is taken off (fig. 3, *h*), before the water reaches the heater and this line is connected with the no-water cut-off. Pressure in the line operates a diaphragm which opens a valve permitting delivery of oil through the pressure regulator. If water delivery is interrupted or the pressure drops below 50 pounds per square inch, the fuel supply to the burner is cut off. Oil pressure is quickly and easily adjusted by a small T-handle screw on top of the pressure regulator.

Vapor pressures are controlled by manipulation of the oil pressure. Oil flow to the burner is also controlled by the manually operated gate valve (fig. 3, *i*) close to the burner. The burner consumed 3½ to 4½ gallons of fuel per hour. By opening the valve *j*, allowing water to flow through the adjustable overflow valve connected to the water line leading to the no-water-cut-off, it is possible to return any desired amount of liquid to the water tank before it reaches the heater coils. This reduces the output of the machine but enables the operator to vary the dryness or quality of the vapor within certain limits.

Temperatures taken by thermocouple near the outlet from the water heater, with the sprayer operating were as follows:

Vapor pressure, pounds per square inch	*Temperature °F.*
100	335
125	350
150	363
175	373

Other readings indicated temperatures of about 275° F. after injection of the chemicals, and about 250° in the spray nozzle just before the spray was released. There appeared to be a drop of about 100° between the water heater and the spray nozzle. However, temperatures still remained high and it was necessary to provide a steam hose of good quality to withstand dragging about the orchards when operating at these temperatures. Armored hose was found to be heavy and difficult to pull. Deterioration of the inner surface caused clogging of some hose. A four-ply, ½-inch steam hose of standard manufacture gave good service, although it was heavy and unwieldy. The hose couplings used are of great importance. They must be of very rugged construction or they cannot be held in place. Additional insulation was required on the hose at the end coupled to the spray

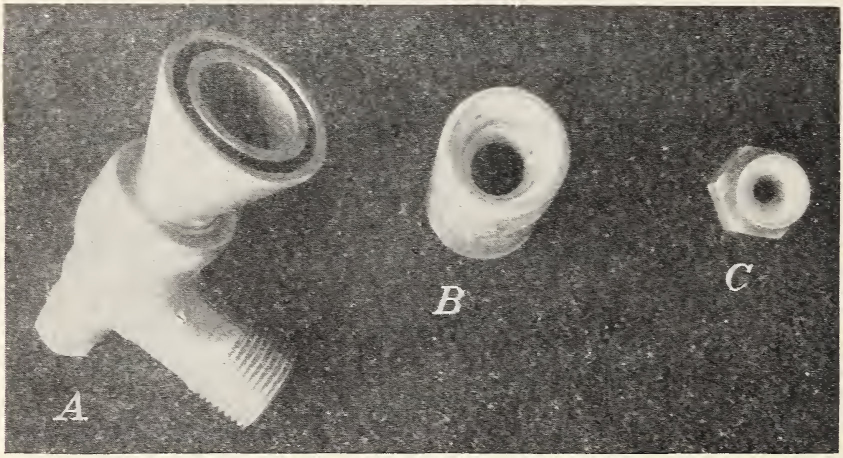

FIGURE 4.—Vapor-spray nozzles: *A*, Vegetable-spraying nozzle; *B*, tree-spraying nozzle; *C*, boom-spray nozzle.

gun. About a foot of this end of the hose was wrapped with ¼-inch cotton sash cord to protect the sprayman's hands from the heat transmitted through the hose. This wrapping can be seen in figure 2 at the handle end of the spray gun.

The spray gun consisted of a 30-inch length of ⅜-inch iron pipe with a brass-ferruled wood grip 24 inches long and 1¾ inches in diameter, fixed to the outside of one end of the pipe. The opposite end of the pipe was fitted with a coupling, and interchangeable 18-inch lengths of pipe could be screwed into this, providing a long or a short gun for spraying vegetation of different heights. The short gun, complete with tree-spraying nozzle attached, is shown in the foreground of figure 2.

The nozzles that gave best results were designed to expand the vapor at a rate that would convert as much of its energy to velocity as possible. Since a satisfactory method of accurately measuring the quality of extremely wet steam was not available, several nozzles were made with small variations in physical dimensions and the one giving least drip or condensation at the exit orifice, and the greatest apparent drive to the issuing spray was selected. Figure 4 shows the three nozzles which it is believed best meet the requirements for tree and

vegetable spraying. The vegetable-spraying nozzle is shown in figure 4, *A*. The throat diameter of the tree-spraying nozzle shown in *B* is three-eighths of an inch, with an exit diameter of twenty-three thirty-seconds of an inch, and length from throat to mouth eleven-sixteenths of an inch. The nozzle *C* was made in three sizes so that different combinations or numbers of nozzles might be attached to equipment using one or more header pipes without exceeding the capacity of the sprayer. Nozzles of this type are used for spraying such crops as grapes and field peas. Their dimensions are given in

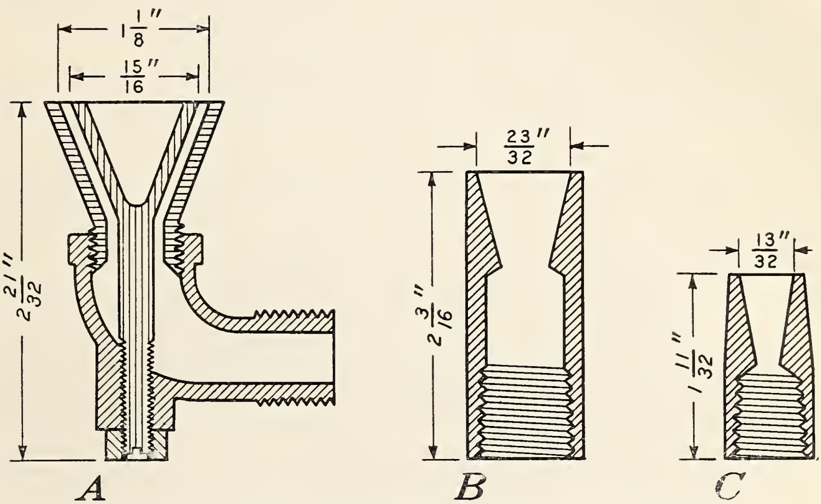

FIGURE 5.—Details of construction of nozzles shown in figure 4.

table 1. The details of construction of the nozzles are shown in figure 5.

TABLE 1.—*Dimension of spray nozzle shown in figure 4, C*

Throat diameter	Exit diameter	Length throat to exit	Over-all length
Inch	*Inch*	*Inch*	*Inches*
1/8	13/32	7/16	1 1/8
5/32	13/32	35/64	1 15/64
3/16	13/32	21/32	1 11/32

A suitable vegetable-spraying nozzle should be designed to produce a spreading spray with a low exit velocity, and as little condensation as possible, since a driving spray will break delicate sprouts or injure tender plants. The nozzle shown in figure 4, *A*, probably met these requirements more satisfactorily than did various other models. The large orifices in these nozzles result in very little clogging trouble. However, Bordeaux and phenothiazene have caused trouble when used in the small nozzles shown in figure 4, *C*. This nozzle, having a throat diameter as small as one-eighth of an inch, would not be suitable for use with either of these materials.

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ORCHARD VAPOR SPRAYING

The field tests of vapor-spray equipment were carried on in commercial orchards to determine whether various materials applied by this machine were as effective for pest control as the same or similar types of materials applied by the usual hydraulic spray methods. All vapor-spray treatments were applied from the ground, and spraying was continued until foliage was thoroughly wetted and run-off was beginning. Plots of apple, peach, and sour cherry trees were sprayed by both types of spray machinery. In most instances the spray materials applied could not be confined to any single material since both insects and disease had to be controlled.

The use of vapor-spraying equipment for control of peach leaf curl, cherry leaf spot, apple scab, and codling moth was studied in Ohio orchards. In February 1937, one application each of five sprays for leaf curl were applied in northern Ohio to peach trees of the Elberta variety which had been severely diseased for the three preceding years. Table 2 shows the materials used and the result of their application in a vapor-spray carrier.

This experiment included several sulfur sprays and Bordeaux. The heat of the vapor spray appeared to reduce the effectiveness of Bordeaux as this material normally applied will control peach leaf curl in Ohio. The reverse is true in the case of dusting sulfur which would not be expected to control leaf curl if applied with a hydraulic sprayer.

The sprays applied to sour-cherry trees were also primarily for the purpose of studying the use of vapor spray as a fungicide carrier. Lead arsenate was added as an insecticide in all sprays. Experiments with vapor spray for cherry leaf spot were carried on for three consecutive years in northern Ohio. The most serious infection occurred during the 1937 season and the disease was most difficult to control during that year. Liquid lime-sulfur which normally gives satisfactory control of the disease, was inadequate when applied with the hydraulic machine. The data recorded in table 3 show the degree of disease control resulting from the use of several materials in the vapor-spray apparatus during 1937.

TABLE 2.—*Control of leaf curl obtained by vapor spraying of peach trees at Painesville, Ohio, 1937*

Spray No.	Spray material per 100 gallons of water	Leaves infected	Control
		Percent	
1	7 gallons of liquid lime-sulfur	(1)	Excellent.
2	15 pounds of dusting sulfur 7½ pounds of lime 2 ounces of gelatin	2	Good.
3	10 pounds of dusting sulfur 5 pounds of lime 2 ounces of gelatin	2	Do.
4	Bordeaux 12-12-100	25	Poor.
5	3 pounds of dry lime-sulfur 12 pounds of dusting sulfur	5	Fair.
6	No fungicide	75	None.[2]

[1] Trace. [2] Most of the leaves dropped in June, and consequently most of the fruit.

TABLE 3.—*Control of leaf spot on cherry trees at Fremont, Ohio, by the use of vapor-spray equipment, 1937*

Type of sprayer	Fungicide per 100 gallons of water	Defoliation due to leaf spot	
		July 10	Sept. 1
		Percent	*Percent*
Vapor	2 gallons of liquid lime-sulfur	5	30
Do	8 pounds of dusting sulfur 2 pounds of lime 2 ounces of gelatin	5	30
Do	6 pounds of dusting sulfur 3 pounds of lime 2 ounces of gelatin	5	40
Do	10 pounds of dusting sulfur 2 ounces of gelatin	5	40
Hydraulic	2 gallons of liquid lime-sulfur	5	70
Check	No fungicide	85	100

It will be seen that the results from using sulfur in vapor-spray machinery appear to be improved in every instance when compared with those obtained from the use of the hydraulic-spray apparatus. Control in vapor-sprayed plots using wettable sulfurs or liquid lime-sulfur was satisfactory. This result was in agreement with the preliminary findings indicating that sulfur was deposited in a finely divided state which adhered to the foliage with greater tenacity than sulfur applied through the usual spray equipment. Insoluble copper compounds applied by the vapor sprayer consistently produced severe foliage injury on sour-cherry trees in both Michigan and Ohio plots. Cherry foliage is relatively easy to wet and the vapor sprayer required about one-third as much liquid as the hydraulic sprayer to adequately cover similar plots of sour-cherry trees.

During 1938 a similar group of sprays for leaf-spot control was applied in a series of vapor-spray experiments in southern Michigan. In general the materials used were sulfur or copper compounds. Bordeaux applied in the Michigan experiments did not satisfactorily control leaf spot. This might have been predicted, since the heat used in producing the vapor appears to darken the color of Bordeaux and to cause it to coagulate. Comparative results of vapor-spray and hydraulic-spray applications made in this work are summarized in table 4.

These data are in agreement with those obtained in Ohio, in that the vapor spray appeared to cause a decrease of the fungicidal effect of Bordeaux and to cause severe foliage injury by the insoluble copper compound, Cupro K. Sulfur flour applied by the vapor sprayer gave as good control as liquid lime-sulfur in the hydraulic sprayer. Lead arsenate was included in all these sprays as an insecticide.

Sulfur compounds have been used extensively against apple scab and a series of experiments using vapor spray as a fungicide carrier against this disease was carried on. On the selected plots in Ohio most of the scab infections, during three seasons, were rather mild. Tests on a fairly severe infection which occurred late in the 1937 season is summarized in table 5.

These sprays were applied to Rome Beauty and Jonathan varieties. Both hydraulic and vapor sprays using liquid lime-sulfur carried 2 gallons of fungicide per 100 gallons of water in the delayed dormant spray with corresponding decreases in fungicide later in the season.

The other materials did not control scab when similarly applied by means of a hydraulic sprayer. No information was obtained relative to the use of vapor spray for codling moth in Ohio because serious infestation did not develop in the orchards in which the spray plots were located.

TABLE 4.—*Control of leaf spot by the use of vapor-spray equipment in the application of certain sprays to cherry trees at Farmington, Mich., 1938*

Type of sprayer	Materials used per 100 gallons of water	Average number of leaves per 100 spurs	Defoliation on shoots
		Number	*Percent*
Hydraulic	3 pounds of Cupro K 2 pounds of lead arsenate	360	11.2
Vapor	3 pounds of Cupro K 2 pounds of lead arsenate	210	38.1
Do	3-4-100 of Bordeaux 2 pounds of lead arsenate	348	16.0
Check [1]	No fungicide	90	71.7
Hydraulic	2½ gallons of liquid lime-sulfur	473	
Vapor	6 pounds of sulfur flour 3 pounds of lime 2 ounces of gelatin 2 pounds of lead arsenate	489	
Check [1]	No fungicide		48.0

[1] Foliage on check infected 100 percent.

A medium infection of apple scab occurred in the plots in southern Michigan which included 35- to 50-year-old trees of Northern Spy, Rhode Island Greening, Northwestern Greening, Jonathan, Ben Davis, and King varieties. Delayed dormant, prepink, pink, calyx, and six cover sprays were applied there.

The amounts of spray liquid applied and the time required to spray these large trees with each type sprayer are shown in table 6 for the pink, calyx, and first cover sprays.

TABLE 5.—*Control of scab obtained by the use of vapor-spray equipment in the application of certain sprays to apple trees at Rittman, Ohio, 1937*

Type of sprayer	Fungicides used	Apples examined	Apples affected by commercial scab	
		Number	*Number*	*Percent*
Vapor	Liquid lime-sulfur [1]	1,064	73	6.9
Do	Dusting sulfur with lime	1,068	18	1.7
Do	Dusting sulfur	1,037	2	.2
Hydraulic	Liquid lime-sulfur [1]	1,157	55	4.8
Check	No fungicide	2,266	1,367	60.3

[1] 2 gallons to 100 gallons of water.

The data in table 6 are typical of sprays applied to fruit trees during the experiments in Michigan. It will be noted that the amounts necessary to suitably wet the foliage when using vapor-spray equipment were from about one-third to one-half as much as were used by the hydraulic sprayer. Vapor spraying one of these trees required more time that the application of a similar hydraulic spray because of the limited capacity of the vapor sprayer. Amounts of spray fluid applied per tree in another series of experiments are given in table 7.

Liquid lime-sulfur was applied to plots as shown in table 8 at the rate of 2 gallons per 100 gallons of water in the first four sprays, beginning with the delayed dormant, and 1½ gallons per 100 gallons of water in the first two cover applications. No fungicides were applied after the second cover spray. One sulfur-flour mixture applied with the vapor sprayer consisted of 6 pounds of sulfur flour, 3 pounds of lime and 2 ounces of gelatin per 100 gallons of water. The other consisted of 8 pounds of sulfur flour and 2 ounces of gelatin per 100 gallons of water. The sulfur flour used was 325-mesh-ground crude sulfur.

Lead arsenate and zinc arsenate were applied at the rate of 3 pounds per 100 gallons of water and napthalene at the rate of 2 pounds per 100 gallons of water as shown in table 8. All plots received the first lead arsenate in the calyx spray. Plots receiving zinc arsenate and napthalene had the lead arsenate replaced by one of these materials beginning with the second cover spray and continuing until six cover sprays had been applied.

Beginning with the second cover spray, five applications of a zinc sulphate-lime corrective were applied on two of the plots treated with the hydraulic sprayer. The rate of application was 4 pounds of zinc sulfate and 4 pounds of lime per 100 gallons of water. A 25-percent flake form of zinc sulfate was used.

TABLE 6.—*Amounts of spray materials and time required for application of spray materials on apples at Farmington, Mich., 1938*

Spray	Vapor sprayer		Hydraulic sprayer	
	Average time required to spray 1 tree	Spray fluid per tree	Average time required to spray 1 tree	Spray fluid per tree
	Minutes	*Gallons*	*Minutes*	*Gallons*
Pink	2.4		1–1½	13.5
Calyx	3.2	6.9	1–1½	15.0
First cover	3.5	6.4	1–1½	18.0

TABLE 7.—*Amounts of spray fluid applied by vapor-spray and hydraulic-spray apparatus to apple trees at Vincennes, Ind., 1937*

Spray No.	Lead arsenate spray		Phenothiazine spray		Nicotine-bentonite spray	
	Vapor	Hydraulic[1]	Vapor	Hydraulic[1]	Vapor	Hydraulic[1]
	Gallons	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*
1	10.5	22	11.0	25	11.5	27
2	12.0	22	10.5	25	15.3	27
3	12.2	22	10.0	25	11.5	27
4	14.3	22	12.2	25	14.4	27
5	10.4	22	14.3	25	13.4	27
6	9.7	22	11.3	25	11.5	27
7	9.7	22	10.9	25	11.2	27

[1] Gallons of spray liquid usually applied in this orchard to trees of this size by hydraulic sprayer.

Data in table 6 indicate coverage was secured in this orchard by the vapor sprayer with approximately half the material ordinarily required when using hydraulic spray machinery.

TABLE 8.—*Control of scab and codling moth, using vapor-spray equipment to apply certain sprays to apple trees at Farmington, Mich., 1938*

Type of sprayer	Materials applied	Average number of worm holes in 100 dropped apples	Average number of worm holes per 100 picked apples	Average number of codling-moth stings per 100 picked apples	Average number of plum curculio feeding and egg punctures per 100 apples	Apples free from insect injury	Fruit showing scab	Average number leaves per 100 spurs, Sept. 9, 1938
						Percent	*Percent*	
Vapor	Sulfur Lime Gelatin Lead arsenate	48.0	10.5	93.9	64.6	38.2	10.0	475
Do	Liquid lime-sulfur Lead arsenate [1] Naphthalene	72.7	30.7	56.6	63.9	32.0	17.4	555
Do	Sulfur Gelatin Lead arsenate	48.0	12.4	93.9	64.6	30.8	10.0	350
Hydraulic	Liquid lime-sulfur Lead arsenate	29.8	12.7	52.6	22.8	49.5	3.3	
Do	Lead arsenate Liquid lime-sulfur Zinc sulfate Lime	26.5	7.3	67.7	29.8	44.9	2.2	539
Do	Zinc arsenate Liquid lime-sulfur Zinc sulfate Lime	69.2	14.5	89.7	25.2	41.4	3.2	620
Do	Liquid lime-sulfur Lead arsenate	22.8	4.7	28.6	34.3	63.0	2.5	356
Check	No fungicide	1356.0	53.2	38.3	525.0	2.7	30.8	491

[1] Lead arsenate used only in first and third cover sprays. Naphthalene in second, fourth, fifth, and sixth cover sprays.

Defoliation of a serious nature did not occur in Ohio, but one of the Michigan treatments, using 8 pounds of sulfur flour and 3 pounds of acid lead arsenate per 100 gallons of water, although it gave best scab control, produced serious defoliation on King, Rhode Island Greening, and Jonathan varieties. This defoliation was probably caused by the arsenical injury. Plots which included lime in the spray showed much less foliage injury. Differences in the Michigan plots became apparent late in July and codling-moth injury could be easily detected in early August. Naphthalene applied in the late cover sprays did not control codling moth as well as lead arsenate.

A study of spray residue was made in connection with the experiments in codling-moth control in southern Indiana. Three types of sprays were applied to Jonathan and Transparent apple trees. These sprays were phenothiazene, lead arsenate in Bordeaux, and nicotine-bentonite, and the vapor sprays were applied from the ground as before. Fungicides for scab control were unnecessary during the vapor-spray work on these plots. The application of one of these sprays for codling-moth control is shown in figure 6. As mentioned previously, foliage was wetted to the point of run-off before it was considered covered.

Referring to table 9, it will be seen that the hydraulic sprays produced heavier deposits, and consequently more toxic material was present on the fruit and foliage between sprays. Analysis of the residue remaining after applying sprays containing phenothiazene indicated deposits were lighter on the vapor-sprayed plots at the time

of application, and this material also appeared to deteriorate more rapidly when applied with a water-vapor carrier. This result was indicated, too, by observation, since the material was visibly changed in color and, compared to the hydraulic sprays, produced a smoother film when dried on the foliage. The toxic deposit appeared to more nearly equal the hydraulic sprays in the case of those containing nicotine-bentonite. The deposit on leaves and fruit from this spray was remarkably smooth and uniform and, as indicated in table 10, was the most promising of the three vapor-sprayed materials in larvicidal efficiency. It will be seen from table 10, however, that in general none of the vapor sprays gave as good codling-moth control as similar

FIGURE 6.—Vapor-spraying an apple tree.

hydraulic sprays. Residue analyses of lead-arsenate sprays, as shown in table 9, indicate the vapor spray did not deposit as much toxic material as the hydraulic machine. This condition is reflected in table 10, which shows lower larvicidal efficiency for the vapor-lead-arsenate spray in most instances. This result was to be expected, since in the average case vapor spray appears to wet foliage with the expenditure of about half as much spray liquid as is required when using conventional hydraulic equipment. This suggested that increasing the concentration of material would enable the vapor sprayer to equal the hydraulic results. Accordingly, the lead-arsenate plot was divided and one portion received a treatment in which the vapor-spray concentration was increased to a point where it was expected amounts of lead arsenate deposited by the two types of sprayers would be about equal. Results from these plots indicated approximately equal results in larvicidal efficiency.

TABLE 9.—*Poison residue deposited by hydraulic and vapor sprayers in milligrams per pound of apples at Vincennes, Ind., 1937*

Spray date	Sampling date	Rain between samples	As_2O_3 [1]		Nicotine [2]		Phenothiazine	
			Vapor	Hydraulic	Vapor	Hydraulic	Vapor	Hydraulic
		Inches	*Milligram*	*Milligram*	*Milligram*	*Milligram*	*Milligram*	*Milligram*
May 24	May 25	----------	7.9	16.0	----------	----------	9.9	10.4
	May 28	(3)	5.4	10.6	----------	----------	6.8	16.1
	June 1	0.23	6.4	9.6	0.42	0.81	1.7	9.2
June 2	June 3	.00	15.1	20.3	4.00	3.50	17.7	34.4
	June 9	1.42	8.3	12.5	1.90	1.60	3.5	8.1
June 11	June 11	.36	16.4	18.2	4.00	4.50	19.1	33.3
	June 21	2.04	5.6	8.9	1.25	2.17	1.2	2.4
June 22–23	June 23	.00	9.9	10.9	3.41	5.58	7.8	24.0
	July 6	.67	----------	6.1	1.50	2.07	2.1	5.3
July 7–8	July 8	(3)	11.8	13.2	1.86	3.41	12.0	29.5
	July 15	.45	----------	9.0	----------	1.60	----------	5.4
	July 19	.23	8.0	8.4	1.40	1.60	2.7	4.5
July 20	July 21	.01	----------	12.4	2.10	2.40	5.3	11.1
	Aug. 2	.16	8.4	9.0	----------	----------	----------	----------
	Aug. 3	.00	----------	8.7	1.11	1.37	2.8	8.3
Aug. 5–6	Aug. 6	.49	----------	15.0	1.24	2.30	4.4	24.7
	Aug. 13	.65	----------	----------	.97	1.87	----------	----------
	Sept. 8	1.92	----------	9.8	.57	1.02	2.5	4.9

[1] Lead arsenate-bordeaux spray.
[2] Nicotine-bentonite spray.
[3] Trace.

TABLE 10.—*Larvicidal efficiency resulting from vapor and hydraulic sprays to apples at Vincennes, Ind., 1937*

Spray date	Sampling date	Rain between samples	Lead arsenate larvicidal efficiency		Nicotine-bentonite larvicidal efficiency		Phenothiazine larvicidal efficiency	
			Vapor	Hydraulic	Vapor	Hydraulic	Vapor	Hydraulic
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
May 24	May 25	----------	20.2	20.0	----------	----------	65.1	60.4
	May 28	(1)	19.3	18.4	----------	----------	33.4	53.9
June 2	June 1	0.23	8.0	23.4	29.0	41.1	15.2	21.5
	June 3	.00	58.9	62.6	75.7	75.2	60.2	87.6
	June 9	1.42	36.6	44.9	50.1	60.5	13.3	39.5
June 11	June 11	.36	62.4	50.7	82.1	82.1	79.8	94.4
	June 21	2.04	26.4	29.1	68.4	70.5	8.6	8.9
June 22–23	June 23	.00	52.2	62.2	87.4	90.0	83.5	99.1
	July 6	.67	----------	29.2	71.5	83.4	10.5	49.7
July 7–8	July 8	(1)	----------	27.9	77.0	80.3	----------	94.8
	July 15	.45	----------	27.7	----------	74.1	----------	74.3
	July 19	.23	----------	25.4	71.0	81.4	----------	65.5
July 20	July 21	.01	----------	29.8	80.4	91.2	71.4	97.7
	Aug. 2	.16	51.4	58.9	----------	----------	----------	----------
	Aug. 3	.00	----------	60.1	83.8	89.1	50.0	93.2
Aug. 5–6	Aug. 6	.49	----------	72.8	84.2	96.3	----------	99.8
	Aug. 13	.65	----------	----------	71.1	86.8	----------	88.5
	Sept. 8	1.92	----------	----------	45.4	69.8	----------	----------

[1] Trace.

VINEYARD AND VEGETABLE VAPOR SPRAYING

Grape rootworm and leaf hoppers are two serious insect pests in northern Ohio vineyards. Several experiments using a one-row boom for applying vapor spray were compared to similar hydraulic-spray applications for controlling these pests. Toxic materials used in the grape-rootworm sprays were calcium arsenate, lead arsenate, phenothiazine, and nicotine-bentonite. Results with the latter in vapor spray were decidedly inferior to those obtained using the material in a hydraulic spray. Relatively high mortality resulted from the

use of arsenates and phenothiazine gave effective kills when applied in vapor spray. There was no injury to fruit or foliage and there did not appear to be any important differences in the final effectiveness of the two methods of spraying for control of this insect.

Vapor spray was also compared to the hydraulic sprayer for control of grape leaf hopper. Nicotine-sulfate in a bordeaux spray was used as the active material. Reference to table 11 indicates the relative effectiveness of the two spray methods.

In this test the hydraulic sprayer applied 31.7 gallons of spray per row, while 9.6 gallons of spray fluid per row were applied by the

FIGURE 7.—Vapor spraying celery.

vapor sprayer. It can be readily seen from the tabular data that control resulting from the vapor-spray application was ineffective since from 17.80 to 35.12 percent of the nymphs remained alive 8 hours after these sprays were applied, whereas from 0.37 to 6.29 percent remained alive after a like period had elapsed in the hydraulic-sprayed plots.

TABLE 11.—*Mortality of leafhopper nymphs resulting from the application of vapor spray to grapes at Vermillion, Ohio, 1938*

Type of sprayer	Grape variety	Nymphs alive before spraying	Nymphs alive 8 hours after spraying	
		Number	*Number*	*Percent*
Vapor	Catawba	1,361	478	35.12
Do	do	883	269	30.46
Do	Concord	1,106	264	23.87
Do	do	1,208	215	17.80
Hydraulic	do	1,341	5	.37
Do	do	1,209	25	2.07
Do	Catawba	986	62	6.29
Do	do	1,062	13	1.22

Most of the vegetable spraying was directed at the control of fungus diseases. A spray is shown being applied to celery in figure 7.

Sprays were also applied to tomatoes, cucumbers, beans, potatoes, and peas. Materials used on peas were for aphid control, with nicotine or the rotenone of ground derris as the toxic agents. The sprays applied to other vegetables were chiefly insoluble coppers and bordeaux, with a sulfur, and a lime-sulfur applied to tomatoes. Results from these materials sprayed on vegetables were similar to those obtained in fruit-tree spraying. Foliage injury produced by insoluble copper compounds used in the vapor sprayer was particularly severe in the bean plots. All of the vegetable sprays were applied by hand except those applied to canning peas. A truck-mounted boom, with a 25-foot canvas trailer covering the nozzles, was used to spray these plots. The trailer was used to confine the vapor as closely to the foliage as possible and to prevent wind from blowing the spray away from the plants as soon as the vapor left the nozzles. Aphid control was unsatisfactory under southern Wisconsin conditions with all of the vapor-spray treatments. Neither nicotine nor derris sprays, nor a combination of the two materials, produced satisfactory control of this insect when used in the vapor sprayer. Amounts of spray liquid applied by the vapor sprayer during the series of experiments ranged from 40 to 104 gallons per acre.

SUMMARY

The field study of vapor-spray equipment utilizing water vapor, for dispersing insecticides and fungicides, has shown desirable as well as undesirable characteristics in spray application by this apparatus. Although coverage of foliage was undoubtedly influenced by the low capacity of the machine compared to the hydraulic sprayers in common use, yet it seems certain that adequate coverage can be secured with vapor apparatus, with the expenditure of less liquid than is required when the ordinary hydraulic sprayer is used. At first thought this appears to be a very decisive advantage. The cost of pumping water for spray work is an important item in both fruit-producing and vegetable-producing enterprises. These experiments indicate that the water utilized for spray work can be reduced from one-third to one-half by the use of vapor-spray equipment. Unfortunately, the experiments also indicate that the cost of operating a portable oil burner of suitable size would probably offset this advantage to the extent that the cost of operation of the two types of spray equipment would be expected to be about equal, if both were in the hands of capable operators.

Observation of the results of applying various materials with vapor-spray apparatus indicates that sulfurs are generally improved in fungicidal action and sticking qualities. There is evidence, however, that the utilization of the heat of the spray liquid in the production of lime-sulfur from a concentrate of lime and sulfur injected into the vapor line is not reliable enough to be suitable for spray work. Under certain conditions it is believed that some polysulfides which are injurious to foliage may be produced by incomplete chemical reactions of these materials while heated in the spray hose. Control of apple scab, cherry leaf spot and peach leaf curl when the trees were vapor-sprayed, using liquid lime-sulfur or inexpensive dusting sulfur, made wettable, was, in practically all cases, equal or superior to control obtained when similar materials were applied with a hydrau-

lic spray. Suitable coverage was secured with small amounts of the sulfur compounds themselves, as well as with a smaller amount of spray liquid. This saving was also considered in comparing the cost of vapor spraying versus hydraulic spraying. Sprays, such as liquid lime-sulfur, which irritate the skin were applied with considerably less discomfort to the sprayman, as there appeared to be less tendency for the drift to coat the face and hands of operators when using the vapor-spray apparatus than when using hydraulic-spray equipment under similar conditions.

Certain materials appeared to be entirely unsuited for use in vapor-spray equipment. Phenothiazine, free nicotines, and Bordeaux did not appear to be able to withstand the heat necessary to produce vapor, without serious deterioration. Fixed nicotines appeared to resist the action of heat somewhat better than free nicotines. All insoluble copper compounds tested were injurious to foliage when applied with this apparatus. Coverage, using lead arsenate in codling moth control was unsatisfactory, since the light, thin coating of material did not protect the fruit. The same amount of toxic material was apparently required to give adequate protection, using either type of sprayer.

An advantage possessed by the vapor sprayer in damp weather was the ability of the finely divided spray to evaporate and dry rapidly after condensation. This enabled the materials to adhere better to fruit or foliage sprayed during very humid weather or when applied shortly before a shower. A mechanical characteristic which is a considerable disadvantage is the necessity for using a heavy heat-resistant hose with rugged couplings capable of withstanding rough field usage when operating at high temperatures. The spray produced at the nozzle is very finely divided and consequently does not carry quite so well under windy conditions as that produced by the ordinary hydraulic sprayer.

Practical spraying for pest control requires a sprayer that is very versatile in its use of materials. Among the several insecticides and fungicides applied in these experiments, sulfur and fixed nicotine compounds were the only two which gave much promise of producing uniformly satisfactory results. Within the region covered by these experiments, the use of vapor-spray apparatus for applying any of the materials used in the spray schedules followed, appears to be limited to possible special cases requiring the application of fixed nicotines or sulfurs.

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